

AD \_\_\_\_\_

Award Number: DAMD17-99-2-9031

TITLE: Minimally Invasive Surgical Research: Endoscopic  
Simulator Development

PRINCIPAL INVESTIGATOR: Gregory L. Merrill

CONTRACTING ORGANIZATION: HT Medical Systems, Incorporated  
Rockville, Maryland 20852

REPORT DATE: April 2000

TYPE OF REPORT: Midterm

PREPARED FOR: U.S. Army Medical Research and Materiel Command  
Fort Detrick, Maryland 21702-5012

DISTRIBUTION STATEMENT: Approved for public release;  
distribution unlimited

The views, opinions and/or findings contained in this report are those of the author(s) and should not be construed as an official Department of the Army position, policy or decision unless so designated by other documentation.

20000824 141

**REPORT DOCUMENTATION PAGE**Form Approved  
OMB No. 074-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing this collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503

|  |   |  |   |                           |
|--|---|--|---|---------------------------|
| 1. AGENCY USE ONLY (Leave blank)   |   | 2. REPORT DATE<br>April 2000                               | 3. REPORT TYPE AND DATES COVERED<br>Midterm(1 Sep 99 - 31 Mar 00) |                           |
| 4. TITLE AND SUBTITLE<br>Minimally Invasive Surgical Research: Endoscopic Simulator Development  |   |  | 5. FUNDING NUMBERS<br>DAMD17-99-2-9031                            |                           |
| 6. AUTHOR(S)<br>Gregory L. Merrill   |   |  |   |                           |
| 7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)<br>HT Medical Systems, Incorporated<br>Rockville, Maryland 20852<br><br>E-MAIL:<br>gmerril@ht.com   |   |  | 8. PERFORMING ORGANIZATION<br>REPORT NUMBER                       |                           |
| 9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)<br><br>U.S. Army Medical Research and Materiel Command<br>Fort Detrick, Maryland 21702-5012  |   |  | 10. SPONSORING / MONITORING<br>AGENCY REPORT NUMBER               |                           |
| 11. SUPPLEMENTARY NOTES<br>Report contains color graphics.   |   |  |   |                           |
| 12a. DISTRIBUTION / AVAILABILITY STATEMENT<br>Approved for public release;<br>distribution unlimited   |   |  |   | 12b. DISTRIBUTION CODE    |
| 13. ABSTRACT (Maximum 200 Words)<br><br>The purpose of this research is to develop minimally invasive procedural simulation technologies that are broadly applicable to the improvement of medical training. The implementation of this technology will enable the Department of Defense (DoD) to provide improved medical support to the wounded soldier through enhanced medical training with improved diagnosis, rehearsal, and treatment planning. This project leverages the involvement of ongoing DoD and civilian work in virtual reality and will improve military readiness through shortened recovery times. It will also lead to the production of commercially viable products with educational and training benefits for U.S. hospitals and medical schools. The specific application chosen for this research was the simulation of flexible ureteroscopy. |   |  |   |                           |
| 14. SUBJECT TERMS  |   |  |   | 15. NUMBER OF PAGES<br>25 |
|  |   |  |   | 16. PRICE CODE            |
| 17. SECURITY CLASSIFICATION<br>OF REPORT<br>Unclassified   | 18. SECURITY CLASSIFICATION<br>OF THIS PAGE<br>Unclassified | 19. SECURITY CLASSIFICATION<br>OF ABSTRACT<br>Unclassified | 20. LIMITATION OF ABSTRACT<br>Unlimited                           |                           |

## FOREWORD

Opinions, interpretations, conclusions and recommendations are those of the author and are not necessarily endorsed by the U.S. Army.

\_\_\_ Where copyrighted material is quoted, permission has been obtained to use such material.

\_\_\_ Where material from documents designated for limited distribution is quoted, permission has been obtained to use the material.

\_\_\_ Citations of commercial organizations and trade names in this report do not constitute an official Department of Army endorsement or approval of the products or services of these organizations.

N/A In conducting research using animals, the investigator(s) adhered to the "Guide for the Care and Use of Laboratory Animals," prepared by the Committee on Care and use of Laboratory Animals of the Institute of Laboratory Resources, national Research Council (NIH Publication No. 86-23, Revised 1985).

N/A For the protection of human subjects, the investigator(s) adhered to policies of applicable Federal Law 45 CFR 46.

N/A In conducting research utilizing recombinant DNA technology, the investigator(s) adhered to current guidelines promulgated by the National Institutes of Health.

N/A In the conduct of research utilizing recombinant DNA, the investigator(s) adhered to the NIH Guidelines for Research Involving Recombinant DNA Molecules.

N/A In the conduct of research involving hazardous organisms, the investigator(s) adhered to the CDC-NIH Guide for Biosafety in Microbiological and Biomedical Laboratories.

  
PI - Signature

Date

**Table of Contents**

**Cover..... 1**

**SF 298..... 2**

**Foreword..... 3**

**Introduction..... 4**

**Body..... 4**

**Key Research Accomplishments..... 8**

**Reportable Outcomes..... 9**

**Conclusions..... 9**

**References..... 9**

**Appendices..... 10**

## **I. Introduction**

The purpose of this research is to develop minimally invasive procedural simulation technologies that are broadly applicable to the improvement of medical training. The implementation of this technology will enable the Department of Defense (DoD) to provide improved medical support to the wounded soldier through enhanced medical training with improved diagnosis, rehearsal, and treatment planning. This project leverages the involvement of ongoing DoD and civilian work in virtual reality and will improve military readiness through shortened recovery times. It will also lead to the production of commercially viable products with educational and training benefits for U.S. hospitals and medical schools. The specific application chosen for this research was the simulation of flexible ureteroscopy.

## **II. Body**

### Overview of Ureteroscopy

A task analysis of ureteroscopy was performed. A flow diagram of this task analysis is in the appendix. Briefly, however, ureteroscopy is the placement of an endoscope into the ureter and up to the kidney. Access to the ureter is obtained by inserting a rigid cystoscope through the urethra and into the bladder. A guidewire is then navigated through the ureterovesical junction. A balloon catheter is used to dilate the distal portion of the ureter where it inserts in the bladder. Occasionally the proximal portion of the ureter must also be dilated. Illustrations of the pertinent anatomy are shown in Figure 1 of Appendix B.

The ureteroscope is navigated through the ureter using both the endoscopic and fluoroscopic views. Both views are essential to this procedure. Contrast is used to ascertain the location and size of the ureteral lumen. The scope may be advanced up to the kidney. Tools may be placed through the working channel to perform a variety of procedures.

To realistically simulate this complicated procedure, the following research tasks were defined in the Statement of Work.

1. Better Methods for Photo-realistic texture mapping
2. Techniques for simulation of physiological events
3. Creation of realistic endoscopic lighting simulation
4. Real-time collision processing
5. Representation of physics of the flexible endoscope
6. Integration of a computer-based geometric model of the urinary tract
7. Tactile/force feedback
8. Instrumentation of the working channel
9. Pathologic/anatomic variations

Our progress to date in each of these areas is discussed below.

#### Better methods for photo-realistic texture mapping

An issue in simulating long, tubular structures is that our graphics rendering hardware requires the visual surfaces to be rendered with texture maps that are square, e.g. 128 x 128 pixels or 256 x 256 pixels. The resultant bit maps, when mapped onto a long structure, are stretched in one dimension in a way that makes it very difficult for the medical illustrators to develop a realistic rendering. We have developed a method of using smaller square bitmaps and tiling them so as to effectively allow the use of rectangular, not square, textures. Initial evaluations of the technique indicate that it will provide good results, while simultaneously minimizing the use of texture memory.

#### Techniques for the simulation of physiological events

We have implemented a real-time fluoro display that models fluid flow and diffusion. Our model is actually a two dimensional (surface) representation of the three dimensional (volume) phenomenon. The model is linked with the actual polygons of the inner surface of the ureter and the calyces of the kidney. Evaluation of the effect has shown that it is viable and that it works well with moving anatomy. In addition, the method enables realistic synchronization of endoscopic and fluoro views. We will be extending the model to accurately reflect interactions encountered in complications such as dissection of the lining of the ureter.

#### Creation of realistic endoscopic lighting simulation

The endoscopic view through a ureteroscope is made complex by a number of phenomena. Saline solution and urine have different refractive indices and different coloration. Lighting projected from the scope tip reflects off the bladder and ureter walls and produces specular reflections whose shapes point in the direction of curvature. Kidney stones have a characteristic surface roughness, and when fragmented for removal, can produce a cloud of small particles, all of which swirl around in the field of view with the fluid flow from the endoscope. Representing these elements realistically could easily require a supercomputer for adequate real time rendering. Our target platform is a 550MHz PIII processor and a hardware accelerated OpenGL graphics card. Our processing budget for setting up the graphics pipeline and rendering is 30 ms (milliseconds), based on a total 67 ms overall frame time. We have therefore experimented with a number of effects that provide a realistic visual simulation while still being able to meet the rendering budget.

To simulate the specular reflection pointing towards the center of the lumen of the ureter, we use environment maps which we move in real-time in concert with a reduced dimensionality model of the scope and ureter. We have modified methods previously developed for representation of mucus on endoscope lenses to produce effects that look realistically like urine and saline mixing. While the visual effect is judged to be good, real time control of the image requires a complex fluid flow model which we have not yet achieved. Our original design involved a simple flow model with a steady stream out the end of the scope that moved in a toroidal pattern – like an elongated smoke-ring. However, we have determined that the visual effects produced by this technique are unrealistic where the flow interacts with the anatomy. We have redesigned this system to incorporate a flow pattern that is warped by a set of control points that are in turn

controlled by a low-order particle system. We will experiment with this design in the next phase of the project.

#### Real-time collision processing

The complexity of the anatomy of the urinary system requires a large number of polygons to represent realistically. The addition of dynamically movable particles, such as kidney stones greatly increases the complexity of the task. We have used a number of techniques to make the collision detection processing manageable. We break the anatomy into a series of viewing/collision groups that are at successively greater distances from the point of insertion. We use these groups as a coarse filter for the collision detection algorithm. Within the collision groups we use oriented bounding boxes (OBB) for objects in an object-to-object collision detection algorithm. This intermediate filter minimizes the number of potential collisions passed to the low level collision detection processing, where point to polygon collision detection processing is performed. We take advantage of the minimal motion of most areas of the anatomy, and combining this with the temporal coherence of scope movement, we have been able to achieve our target 20 ms collision detection processing in most areas of the model.

#### Representations of the physics of the flexible endoscope

The problem of simulating the physics of the flexible endoscope is complicated by the interaction of the scope with instruments placed through the working channel of the scope. During initial navigation, we assume a navigational wire has already been placed in the ureter. The scope is then threaded over the navigational wire through the urethra into the bladder and then into the ureter. We have created a combination physics model for the scope based on a rigid body representation of the individual segments of the scope. We use penalty forces to represent forces from the anatomy on the scope and then solve a set of ordinary differential equations using a second or forth order Runge-Kutta method. We compute corrective forces on the rigid body links to enforce rigid length constraints on the scope elements, then move forward one time step. For stability and realism we limit both acceleration and velocity. At each time step, we compare the dynamic solution with a static equilibrium solution computed using the principle of virtual work. We then use the amount of difference as a measure of stability. If instability is detected we increase a set of damping parameters until the dynamic solution is sufficiently close to the static solution.

We have constructed a number of alternative physics based models of general purpose endoscopes and evaluated them for stability across the range of input motions that are anticipated in procedures of this type. We have devised a two level deformation and interaction model to obtain adequate speed and responsiveness. A global model is used to quickly compute macro deformation of the bladder and ureter, and to compute the forces transmitted by the scope back to the practitioner, and a micro model is used for computation and display of the localized, small deformations of the anatomy caused by the tip of the scope or tools inserted through the working channel. We are using an innovative application of dynamic B-Splines that permits adaptable inertia, elasticity, and damping parameters to be applied on a local or global basis in response to modeled physiological effects.

During the last quarter, we constructed a number of alternative physics based models of general purpose endoscopes and began evaluation of their stability and effectiveness in modeling the physics of ureteroscopic interactions. We have successfully refined our modeling system and can now interactively change the physical properties of the scope, catheter, and navigational wire in real-time, allowing simulation of the interchange of catheters, wires, and scopes in arbitrary sequence in the simulation. We have achieved good stability in the system under most conditions, but have some instability under unusual situations such as rapid rotation of the guidewire. We believe the system is sufficiently stable for realistic motions, and will confirm this with physician feedback during alpha evaluation.

#### Integration of a computer-based geometric model of the urinary tract

We have developed a model of the urinary tract including the urethra, the bladder, the ureter, and the calyces of the kidney. We developed the model using a nurbs-based modeling tool, then used a custom tool to produce a polygonal model that has the capability of deforming with tool/anatomy interaction. We augment the resultant data structure with a number of additional indices which are implemented as threaded lists of pointers that enable traversal of the model in a non-linear fashion. These are produced with an offline utility and enable us to quickly access neighboring polygons and vertices to speed up real-time collision detection between the scope, the wire, and the anatomy

#### Tactile/force feedback

We have designed a number of testbeds for evaluation of alternative means of adapting our haptic interface devices to enable the application of a range of working channel tools with realistic sensations of touch and feel on both the scope and the working channel simultaneously. We have implemented a mechanism for providing force feedback from within the body of the scope itself and will be evaluating the efficacy of that mechanism in comparison with application of forces at the tip of the working channel tool. Of particular concern is the ability to couple the forces displayed on the two devices with motions of the devices relative to each other. We earlier reported that we had devised and were evaluating a two level haptic feedback system which combines a 1000 Hz primary feedback loop implemented in an external microprocessor with a 100 Hz global feedback loop implemented in the simulation computer. This combination is intended to allow us to realistically and accurately display complex forces such as those associated with the use of a basket while simultaneously manipulating both the scope and the basket.

In our evaluation of this two-processor approach, we have found that the force feedback mechanism for the wire is highly responsive. However, we have had continuing problems with getting sufficient precision in the input from device encoders. What was originally thought to be errors in the microcode of the controller that cause it to lose an order of magnitude in reported precision are actually design incompatibilities between the microcontroller and the system driver software. We have specified a new design that will unfortunately not be available until the October timeframe. Therefore we have had to fall back to a design using only the computer processor. This limits our haptics loop to only 100 Hz, but we feel this will be adequate. Our implementation will have an alternate



interface for the higher speed loop provided in the external processor should we be able to achieve that design in the future.

#### Instrumentation of the working channel

We are in the process of modifying a design for working channel force feedback originally developed for flexible bronchoscopy to fit within the reduced size handle of the ureteroscope. An initial version is being produced for incorporation in Alpha evaluation testbed.

#### Pathologic/anatomic variations

A major issue in medical simulation development is the difficulty of producing new case studies. We have addressed this problem by developing a set of modeling tools that enable us to quickly model a new case from scratch or to modify an existing case. This has reduced our turnaround time on production of alternative case studies significantly, and enabled a much more effective interaction between modelers and medical experts. We have worked on a method for dynamically inserting pathologies into the model but have not been able to solve some low-level compatibility problems. We have developed a technique for "stitching" in a pathology or anatomical variation in a given place in the anatomy. The technique involves producing a polygonal mesh model with a set of base or edge vertices which must be merged with the underlying polygonal anatomical model. In addition to the base mesh where it will be stitched into the anatomy, the pathology model includes a set of orientation vectors. These include a normal vector which after placement should be roughly perpendicular to the average surface normal of the local anatomy along with an axial orientation vector after placement should be approximately parallel to the axis of local lumen of the anatomy, for example the ureter. We indicate an approximate area where the pathology should occur, then use a local search procedure to find the polygon that comes closest to containing each vertex. We find the point on that polygon that is nearest the stitch vertex and from that point place an additional vertex there, then warp that vertex up (or down) to the position of the stitch vertex. This has the effect, for each stitch vertex, of adding two new triangles to the mesh at that point. The technique works well, but has some residual artifacts. In particular, overall scaling of the pathology is unrealistically affected by local anatomical variations. We are working on a technique to make the pathology exist in it's own reference frame whereby it's shape is invariant even in the presence of severe surrounding anatomical movement.

#### Prototype Simulator

Our progress of the above mentioned tasks has enabled us to construct a prototype simulator. This simulator will be demonstrated at the upcoming American Urological Associations Annual Meeting, which will be held April 30-May 4, 2000.

### **III. Key Research Accomplishments**

- Produced task analysis of flexible ureteroscopy
- Integrated simulated fluoroscopic and endoscopic displays
- Advanced contrast fluid flow algorithms
- Developed several physics-based models of flexible endoscope

- ❑ Constructed of an computer-based geometric model of the urinary tract from CT data sets
- ❑ Developed set of modeling tools that enable efficient development of anatomic and pathologic variations
- ❑ Built prototype ureteroscopy simulator

### Reportable Outcomes

1. Tasto JL, Verstreken K, Brown JM, Bauer JJ. PreOp™ Endoscopic Simulator: From Bronchoscopy to Ureteroscopy. *Proceedings of Medicine Meets Virtual Reality 2000*; Newport Beach, CA; January 27-30, 2000; 344-349. See appendix C.
2. Tasto JL, Bauer JJ, Verstreken K, Brown JM, Merrill GL. Training Simulator for Endoscopic Procedures. *American Telemedicine Association Fifth Annual Conference and Exhibit Showcase*; Phoenix, AZ; May 21-24, 2000; (abstract accepted). See appendix D.

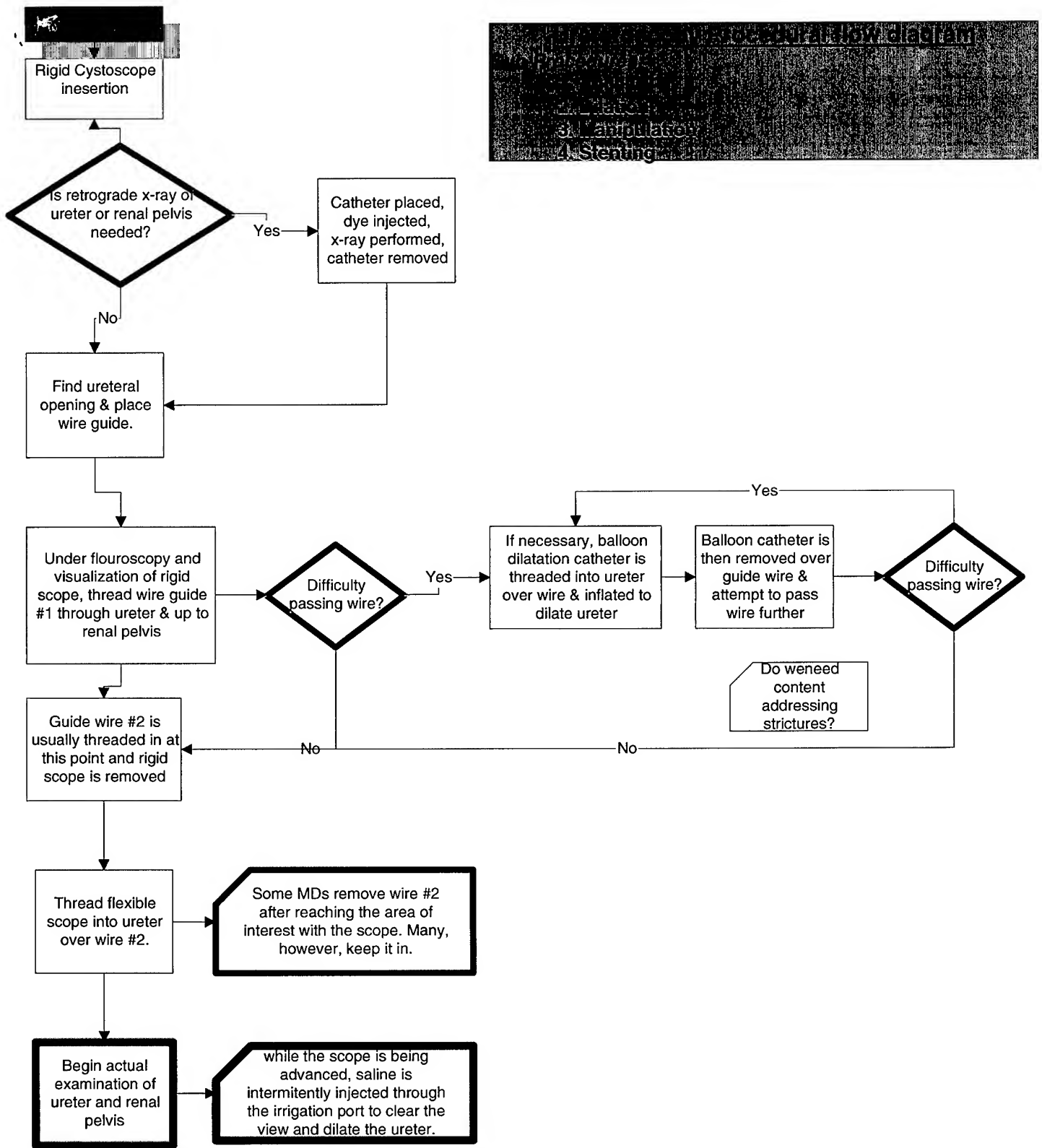
### Conclusions

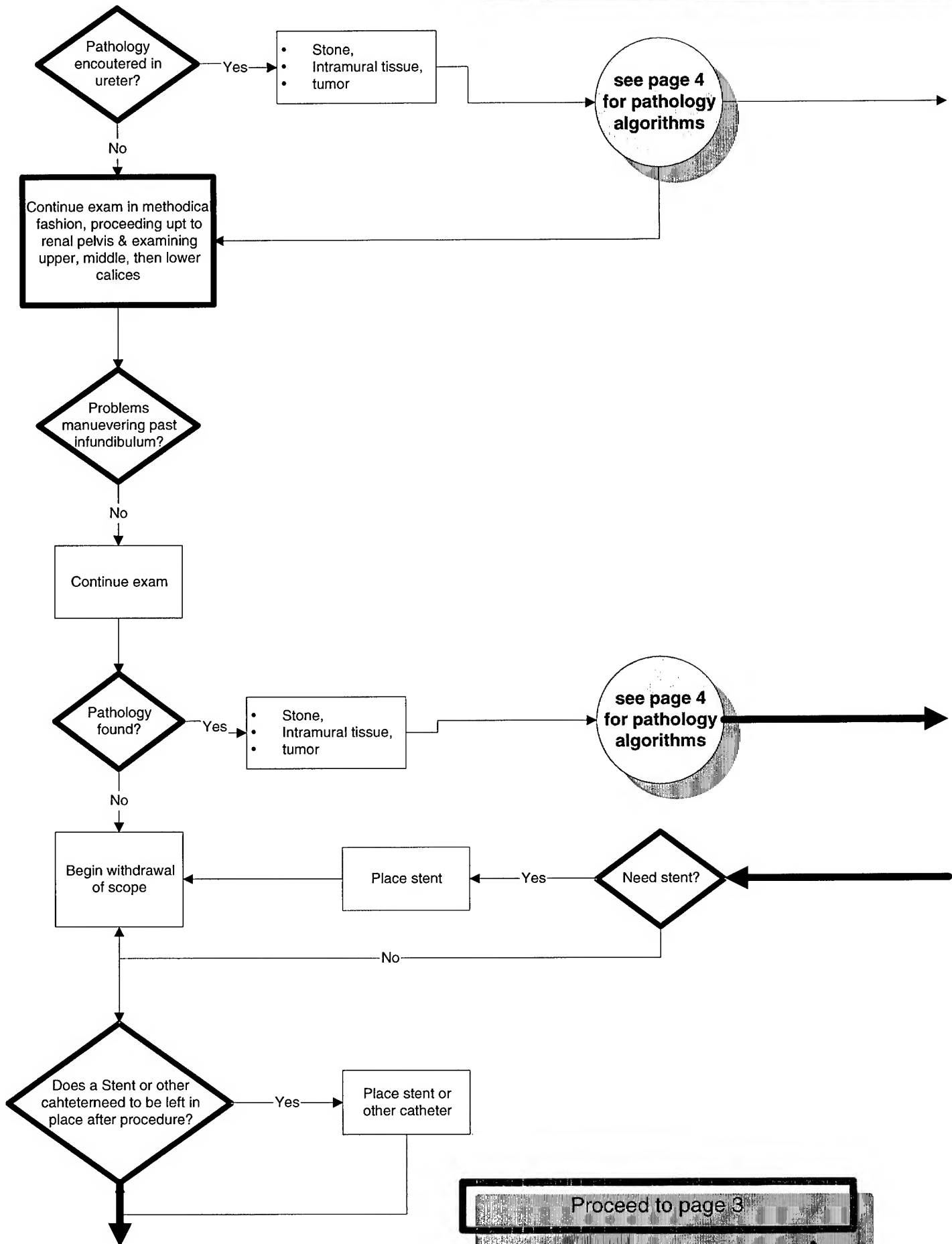
The research conducted during the first 6 months of this Award has allowed us to develop a prototype ureteroscopy simulator. This prototype will be demonstrated at the American Urological Association's (AUA) Annual Meeting, which will be held April 30-May 4, 2000. At this meeting, feedback on this prototype will be obtained from physicians with expertise in flexible ureteroscopy. This feedback will be used to guide the remaining development on this project. A final version of the simulator will be delivered to the Army by the end of the development period (8/31/00).

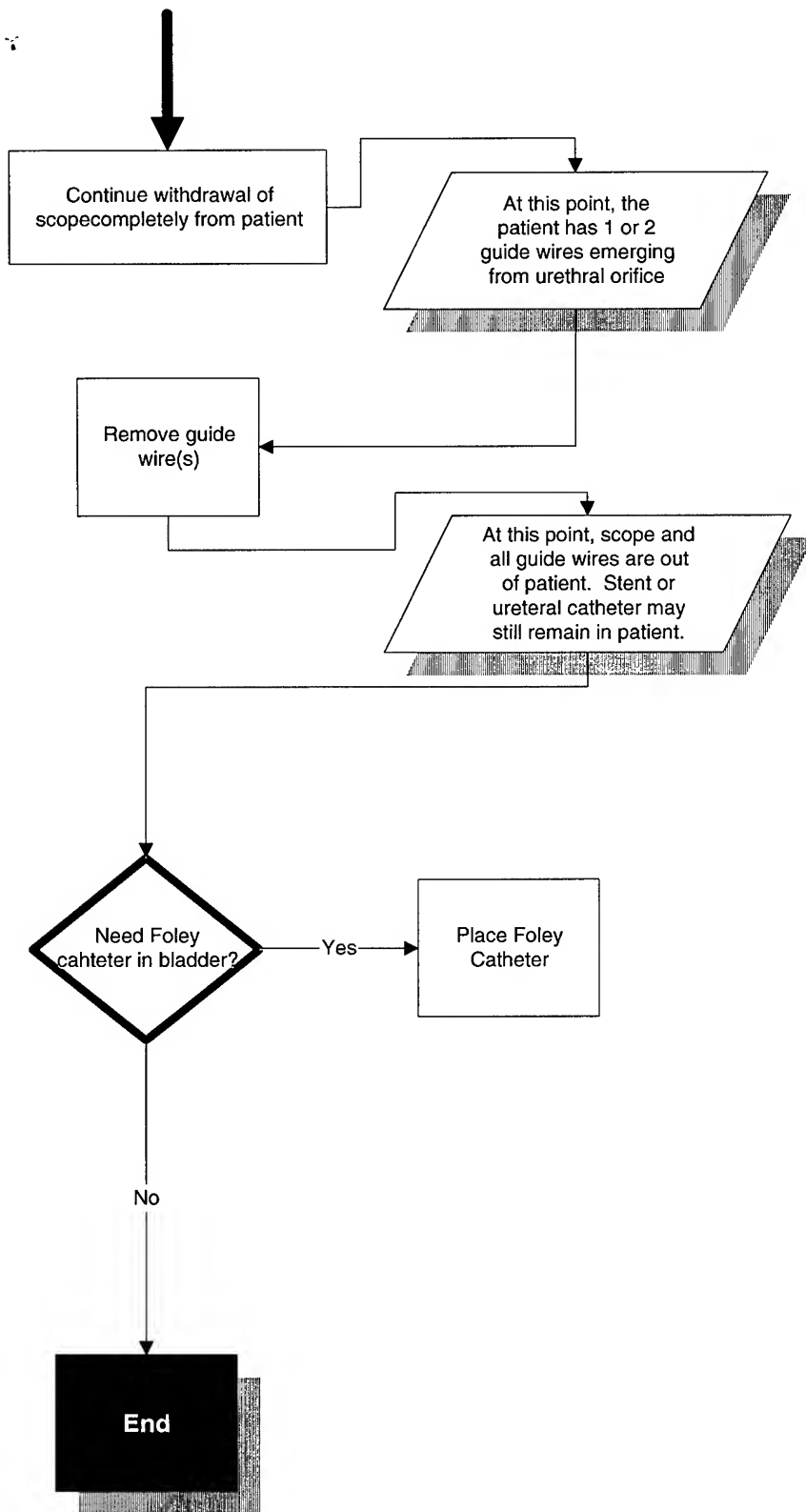
### References

1. Tasto JL, Verstreken K, Brown JM, Bauer JJ. PreOp™ Endoscopic Simulator: From Bronchoscopy to Ureteroscopy. *Proceedings of Medicine Meets Virtual Reality 2000*; Newport Beach, CA; January 27-30, 2000; 344-349.
2. Tasto JL, Bauer JJ, Verstreken K, Brown JM, Merrill GL. Training Simulator for Endoscopic Procedures. *American Telemedicine Association Fifth Annual Conference and Exhibit Showcase*; Phoenix, AZ; May 21-24, 2000; (abstract accepted).

## **Appendix A: Ureteroscopy Task Analysis**







## Algorithm for Stone found in Ureter

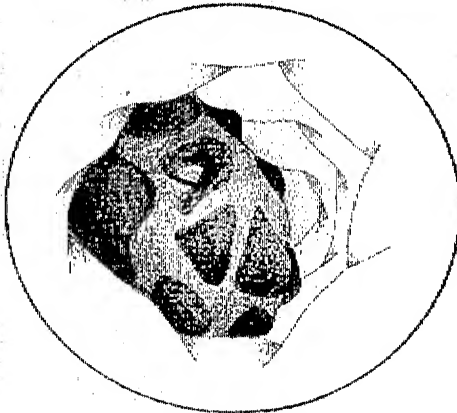
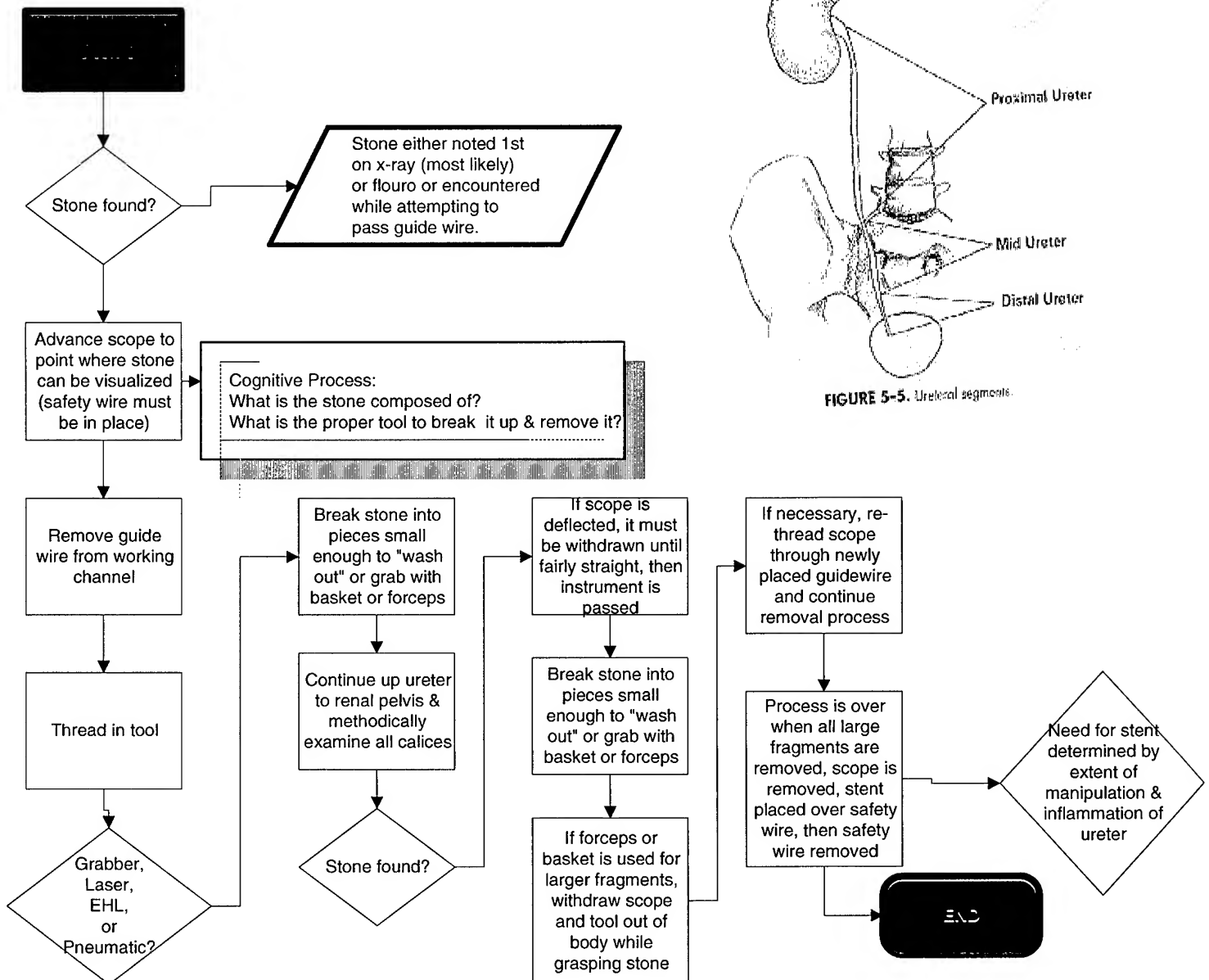


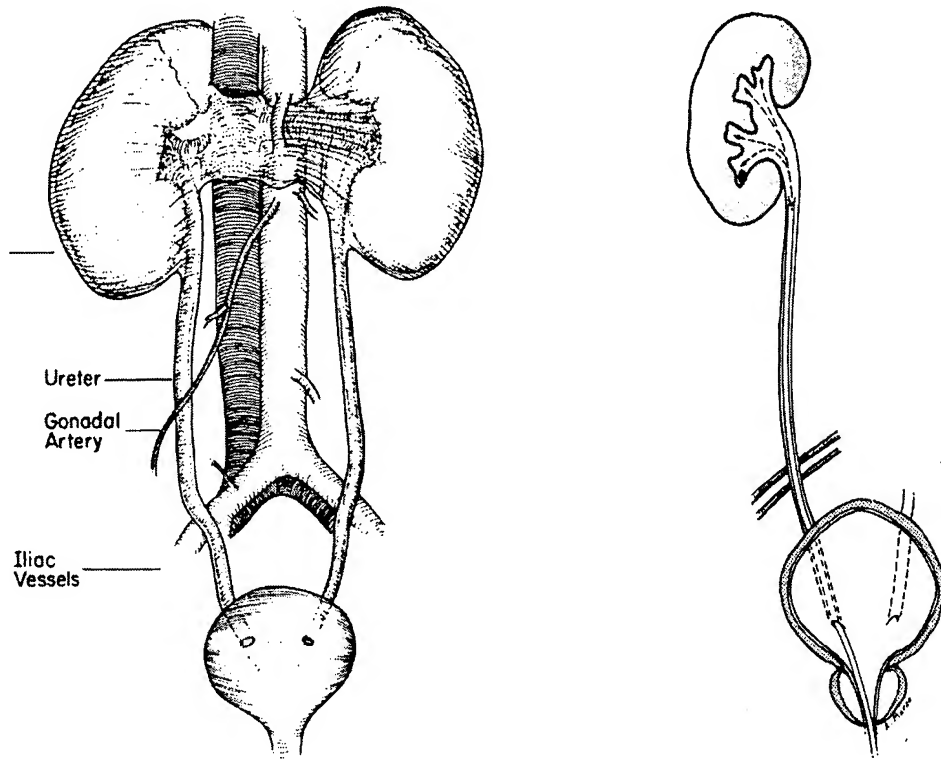
Figure 6.1. A schematic of a calcium oxalate monohydrate ureteral calculus. Access is first obtained in a retrograde fashion



Figure 6.2. A trans-illuminated ureter stone composed of calcium oxalate monohydrate



## Appendix B: Relevant Anatomy for Ureteroscopy





**Appendix C: MMVR Paper**

## PreOp™ Endoscopy Simulator: From Bronchoscopy to Ureteroscopy

JOSEPH L. TASTO, M.D., M.S.; Kris Verstreken, M.D., M.S.; J. Michael Brown, Ph.D.;  
John J. Bauer, M.D.\*

*HT Medical Systems, Inc., 55 W. Watkins Mill Road, Gaithersburg, Maryland 20878*

*\*Telemedicine and Advanced Technology Research Center (TATRC), Ft. Detrick, Maryland*

**Abstract:** The high cost of virtual reality simulators has posed a major obstacle to the widespread adoption of simulators for medical training. HT Medical broke through this cost barrier by developing the PreOp™ Flexible Bronchoscopy simulator, a realistic training simulation system that integrates force feedback, multimedia, and 3D graphics on a PC. We are currently extending the PreOp platform so that it can simulate other endoscopic procedures. This paper discusses our efforts to extend the platform to simulate flexible sigmoidoscopy and ureteroscopy.

### 1. Introduction

The high cost of virtual reality simulators has posed a major obstacle to the widespread adoption of simulators for medical training. HT Medical broke through this cost barrier by developing the PreOp™ Flexible Bronchoscopy simulator, a realistic training simulation system that integrates force feedback, multimedia, and 3D graphics on a PC.[1] This system, which became a commercially available product in the spring of 1999, consists of PC-based software, a proxy flexible bronchoscope and a robotic interface device that tracks the scope and provides force feedback to the user.



Figure 1: HT Medical's PreOp™ Flexible Bronchoscopy Simulator

We are currently extending the PreOp platform so that it can simulate other endoscopic procedures. This will allow the cost of the simulator to be shared across departments at medical schools and hospitals, accelerating the introduction of the PreOp simulator into the clinical setting. This paper discusses our efforts to extend the platform to simulate flexible sigmoidoscopy and ureteroscopy.

## 2. Medical Analysis

### 2.1 Flexible Sigmoidoscopy

The goal of flexible sigmoidoscopy is to inspect the colon for pathologic lesions using an endoscope. Often this is performed as a screening exam for colorectal cancer. There are two distinct stages of the exam. The first stage consists of advancing the sigmoidoscope from the anus to the point of maximum insertion. The point of maximum insertion depends on many factors such as the scope length, the patient's anatomy, and the level of patient discomfort. However, a 60-cm scope can usually reach the splenic flexure, which is where the transverse colon and the descending colon meet. The second stage of the procedure consists of carefully examining the mucosal walls of the colon as the scope is slowly withdrawn.

Simulating flexible sigmoidoscopy is more challenging than bronchoscopy for several reasons. Table 1 summarizes some of the pertinent differences between bronchoscopy and sigmoidoscopy. Of particular note is that the tracheobronchial tree is relatively fixed and rigid compared to the elastic and mobile colon. These differences greatly increase the computational time, which is a paramount problem given the constraints of 15-30 frames per second for real-time simulation. In addition, the sigmoidoscope is twice the diameter of the bronchoscope and has additional controls, such as left/right tip control and a two-state air/water insufflation button.

Table 1: Comparison of Significant Differences between Bronchoscopy vs. Sigmoidoscopy

| Procedure Feature            | Bronchoscopy                               | Sigmoidoscopy                     |
|------------------------------|--|-----------------------------------|
| Local Anatomy                | Rigid<br>Smooth Mucosa                     | Elastic<br>Mucosal Folds          |
| Global Anatomy               | Fixed<br>Complex branching pattern         | Mobile<br>Single tube             |
| Local Physiological Motions  | Bronchial spasm<br>Heart/aortic pulsations | Colon spasm                       |
| Global Physiological Motions | Respiratory motions                        | Peristalsis                       |
| Scope Length                 | 55 cm                                      | 60 cm                             |
| Scope Diameter               | 6.0 mm                                     | 12.2 mm                           |
| Scope Tip Control            | Up/Down                                    | Up/Down<br>Left/Right             |
| Scope Buttons                | Suction                                    | Suction<br>Air/Water insufflation |

### 2.2 Flexible Ureteroscopy

Ureteroscopy is performed to remove kidney stones, fragment large kidney stones (lithotripsy), biopsy a tumor, or remove stents. The goal of ureteroscopy is to navigate the

endoscope from the entrance of the urethra, through the bladder, into the ureter, and up to the calyces of the kidney. Access to the ureter is typically obtained by inserting a rigid cystoscope through the urethra in the penis or vagina and into the bladder. A guidewire is then navigated through the ureterovesical junction (where the ureter empties into the bladder). A balloon catheter is used to dilate the distal portion of the ureter where it inserts in the bladder. Occasionally the proximal portion of the ureter must also be dilated. The flexible ureteroscope is then advanced over the guidewire and into the ureter. The scope can be advanced up to the kidneys and procedures performed.

Ureteroscopy presents unique challenges over and above bronchoscopy and sigmoidoscopy. From a simulation standpoint, ureteroscopy can be thought of as a hybrid between bronchoscopy, sigmoidoscopy, and angioplasty. Like the tracheobronchial tree, the calyces of the kidney branch extensively, allowing for multiple paths. Like sigmoidoscopy, the ureter is a single distensible tube. Like angioplasty, ureteroscopy requires fluoroscopy, contrast injection, balloon catheters and guidewires. Thus ureteroscopy requires a system that incorporates simulation technology from bronchoscopic and sigmoidoscopic simulation, as well as from HT Medical's PreOp™ Endovascular Simulator (shown in Figure 2). We have chosen to simulate the endoscopic portion of ureteroscopy first and then add the endovascular features. Therefore, this paper will limit the discussion to endoscopic simulation.



**Figure 2:** HT Medical's PreOp™ Endovascular Simulator

### 3. Software Design

The tasks for the software can be broadly defined as (1) receive information from the user through the software interface and hardware interface, (2) perform the necessary computations that the user's actions require, and (3) control the resulting visual, tactile, and auditory feedback that the user receives. For example, (1) the user translates the proxy sigmoidoscope 5 cm; (2) the software then computes the consequence of this action (e.g., collision of the scope with the mucosal wall); (3) a "red-out" is displayed in the endoscopic view, the virtual patient says, "ouch," and the robotic interface device provides a resistive force that is felt by the user.

#### 3.1 Flexible Sigmoidoscopy

From a computer-modeling standpoint, the most significant difference between bronchoscopy and sigmoidoscopy is that the tracheobronchial tree is a relatively rigid and fixed structure, while the colon is much more elastic and mobile. These differences are

outlined in Table 1. Cartilaginous rings and plates support the bronchi, whereas the colon has no such rigid support. The tracheobronchial tree does not twist, rotate, and loop like the colon does.

The key element in the software design is therefore realistic modeling of the colon, the flexible sigmoidoscope, and the colon-scope interaction. This modeling can be divided into global and local modeling tasks. Global modeling defines the interaction between the entire scope and the entire colon model. Local modeling concentrates on the interactions between the scope tip and portion of the colon that is located in the immediate environment of the scope tip (which is where the scope view originates).

Examples of behaviors handled at the global level are formation of loops in the colon (e.g., alpha loops or N-loops), changes in length and diameter of the colon with suction and insufflation of air, shortening/lengthening of the colon due to compression/expansion of the haustral folds in an accordion-like fashion (i.e. "sleeving up the colon"), and "paradoxical movement" of the scope tip (scope tip retracts as scope shaft is advanced).

Examples of behaviors handled at the local level are deformation of the colon wall in response to pressure from the tip of the scope, "red-out" of the display when the scope tip pushes against the colon wall, the scope's interaction with mucosal (haustral) folds or other detailed structures such as polyps, and force feedback resulting from interaction of scope tip with the colon wall

### 3.2 Flexible Ureteroscopy

As mentioned above, flexible ureteroscopy requires the use of several simulation techniques. Therefore, we have chosen to divide the approach into three categories, based on the specific challenges posed by the different anatomical structures to be modeled. For the bladder, accurate modeling of wire dynamics is necessary for the navigation of the guidewire into the ureter and dilatation of the distal ureter with a balloon catheter. The ureter has properties similar to the colon and will thus be modeled using the global/local approach described above for flexible sigmoidoscopy. The kidney requires an emphasis on path finding because of the branching pattern of the calyces. Accurate collision detection is necessary to constrain the scope to the chosen path.

## 4. Hardware Design

Our present endoscopy simulator comprises a computer, a display monitor, and the AccuTouch™ Endoscopic Interface Device (patent pending). The interface device consists of a proxy endoscope that looks like a real endoscope and is electrically connected to the second part of the interface device, a robotic "mannequin" into which the endoscope can be inserted. Various sensors, detailed below, track the state of the system and send this information back to the host computer via a data cable. The simulation uses this state information to compute appropriate visual and tactile responses to the motions imparted by the user. These responses are transmitted to the user through visual, audio and haptic modalities, creating a powerful illusion for the user that he/she is inserting the endoscope into a real patient.

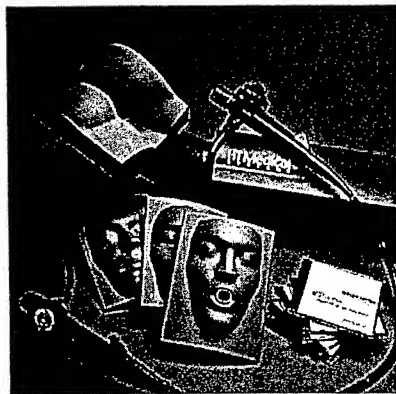


Figure 3: PreOp interface device

The endoscopy "mannequin" approximately represents the anatomical insertion site, accepts any of several proxy scopes, tracks scope insertion and rotation, and provides force feedback through the endoscope to the user's hands. Representation of the anatomical insertion site is achieved through use of a detachable local anatomic model, which is user-adjustable into horizontal, sideways, or vertical configurations.

The robotic "mannequin" has been designed to accept proxy bronchoscopes, sigmoidoscopes, colonoscopes, gastroscopes, and ureteroscopes through the appropriate anatomic models. Tracking of scope motions is achieved with sensors that monitor insertion and rotation of the scope tube, while electrical actuators provide translational and/or rotational force feedback based on the state of the endoscopy simulation.

The bronchoscope was designed to look and feel like a real scope, with the same controls, force feedback, and scope tube as the real medical tool. It accepts a proxy working channel tool, tracking both tool translation and rotation, and provides translational force feedback to the user. The scope also tracks the motion of the thumb lever, and monitors the state of the suction button and video control buttons, making that information available to the simulation. These sensor readings and actuator commands are transmitted to the host computer via a custom data cable, which looks and feels like the video/light source cable that normally is attached to the scope.

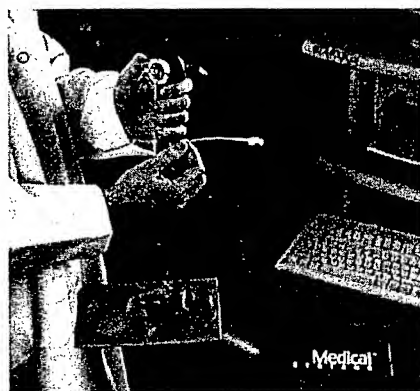


Figure 4: Manipulation of working channel tool

#### 4.1 Flexible Sigmoidoscopy

We have developed a sigmoidoscope following similar design guidelines. As with the bronchoscope, the sigmoidoscope accepts a proxy working channel tool, tracking its translation and rotation, and providing translational force feedback to the user. The scope tracks the two knobs that control up/down and left/right motion of the scope tube tip, and has locking mechanisms as in the real scope. In addition to the suction and video control buttons, the sigmoidoscope has a two-stage button for controlling air insufflation and water instillation. These sensor readings, along with the actuator commands, are transmitted back to the host computer through the same type of data cable as with the bronchoscope.

#### 4.2 Flexible Ureteroscopy

Currently in development, the proxy ureteroscope will incorporate many of the features described above. As in the previous cases, the scope will need to track its working channel, along with the control levers and buttons. Subtleties of the design include accommodating the smaller diameter scope tube (3.2mm, as opposed to 5.3mm for the bronchoscope and 12.2mm for the sigmoidoscope) and incorporating the use of guide wires and balloon catheters during the procedure.

### 5. Conclusion

The PreOp Endoscopy Simulator was designed to be modular in nature so that all endoscopic procedures could be simulated on the same software and hardware platforms. The first endoscopic procedure simulated on the PreOp platform was flexible bronchoscopy. This simulator is commercially available and has been sold both in the United States and internationally. We are currently developing modules for flexible sigmoidoscopy and flexible ureteroscopy. These additional modules will allow the cost of the system to be shared across medical specialties, thus making the system affordable and accelerating the use of simulation in the medical setting.

### 6. Acknowledgements

This research was funded in part by the Department of the Army under Cooperative Agreement No. DAMD17-99-2-9031. The U.S. Army Medical Research Acquisition Activity, 820 Chandler Street, Fort Detrick, MD 21702-5014 is the awarding and administering acquisition office. The content of this publication does not necessarily reflect the position or the policy of the Government, and no official endorsement should be inferred.

### References

- [1] Bro-Nielsen M, Tasto JL, Cunningham RL, Merrill GL. PreOp™ Endoscopic Simulator: A PC-based immersive training system for bronchoscopy. In: *Proceedings of Medicine Meets Virtual Reality 7*; San Francisco, CA; January 20-23, 1999; 76-82.

## **Appendix D: ATA Abstract**



## **Training Simulator for Endoscopic Procedures**

Joseph L. Tasto, M.D., M.S., John J. Bauer, M.D. \*, Kris Verstreken, M.D., Ph.D., J. Michael Brown, Ph.D., Greg Merrill

HT Medical Systems, Inc., Gaithersburg, Maryland

\*Telemedicine and Advanced Technology Research Center (TATRC), Ft. Detrick, Maryland

Medical simulators offer the potential to improve medical training, decrease costs, and provide objective measurements of procedural competence for credentialing and certification. However, the two biggest challenges to the adoption of this technology has been the high cost and inadequate realism associated with this technology. Until recently, computer-based simulations required expensive high-end computers to maintain the real-time frame rates necessary for realistic simulation.

These challenges were overcome with the introduction of HT Medical's PreOp™ Flexible Bronchoscopy simulator, a realistic training simulation system that integrates force feedback, multimedia, and 3D graphics on a PC. This presentation will focus on the research and development efforts underway to extend this simulation system to other endoscopic procedures, such as ureteroscopy and flexible sigmoidoscopy. We describe the trade-offs and solutions that we developed to overcome the challenges of simulating the wide variety of endoscopic procedures on the same hardware and software platform.

Dr. Tasto has a unique background in medicine, engineering, and medical education. He has a Bachelor of Electrical Engineering, a Master of Science in Electrical and Computer Engineering, and Doctor of Medicine degree. Prior to joining HT Medical, Dr. Tasto was involved in innovative curriculum development for medical training. He has worked as an engineer in the field of medical imaging systems simulation. In addition, Dr. Tasto developed simulation software while employed at General Motors. He has published in the fields of medical simulation systems, medical education, emergency medicine, and electrical engineering.